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LIGHTCURVES OF HST-1 IN M87

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RESUMEN

El movimiento de nudos en jets astrofísicos es comúnmente interpretado como ondas de choque moviéndose a lo largo de éstos. Observaciones multifrecuencia del nudo HST-1 en extensos periodos de tiempo producen complicadas curvas de luz, las cuales son difíciles de modelar con codigos hidrodinámicos estándar. En este trabajo reproducimos estas curvas de luz, usando el enfoque semi-analítico dado en Mendoza et al. (2009), desarrollado para reproducir curvas de luz de superficies de trabajo moviéndose a lo largo de jets relativistas. En particular usamos este enfoque para reproducir las exóticas características observadas en las curvas de luz del nudo HST-1 en M87. Mostramos que los complicados ajustes de las curvas de luz se reproducen con gran precisión en todas la longitudes de onda, cuando se considera que estas superficies de trabajo son generadas por oscilaciones periódicas en la velocidad del flujo y masa inyectada en la base del jet.

ABSTRACT

The motion of knots in astrophysical jets is commonly interpreted as shock waves moving along it. Observations of the HST-1 knot during extended periods of time have produced complicated light curves on many wavelengths which are difficult to account using standard hydrodynamical models. Here we reproduce these light curves using the semi-analytical approach by Mendoza et al. (2009), developed to reproduce light curves of working surfaces moving along relativistic jets. These working surfaces are generated by periodic oscillations of the injected flow velocity and discharge at the base of the jet. In particular, we use this approach to reproduce the exotic observed features of the light curves of the HST-1 knot in M87. We show that the complicated fits to the light curves are reproduced with high accuracy in all wavelengths.

Key Words: galaxies: active — galaxies: jets

1. INTRODUCTION

Chandra Observations of the HST-1 knot (Harris et al. 2006) in M87 showed that a peak in the X-ray light curve developed about 2005. This light curve has since shown successive peaks over short periods of time. Observations in UV (Madrid 2009) and radio (Chang et al. 2010) have also shown the same trend. Since quasi-periodic signatures in the brightening and dimming of the HST-1 knot X-ray observations were found by Harris et al. (2009), these show a manifestation of a previous modulation in the jet power, most probably a local oscillation of the process that converts the bulk kinetic jet power to internal energy of the emitting plasma.

In this work we take multi-wavelength observations from HST-1 knot. For instance, the X-rays observations are part of a multi-frequency program coordinating the Chandra and HST monitoring by Harris et al. (2009). The ultraviolet data are part of the observations carried out during the years 1999 to 2006 (Madrid 2009). Finally the radio data corresponds to observations with the VLBI at 2 cm (Chang et al. 2010). All these observations reveal a clear multi frequency light curve of the HST-1 knot which serves as a laboratory to test the ideas developed by Mendoza et al. (2009) for the formation and propagation of the working surface of a relativistic jet, with periodic variations of the injected velocity profiles and mass rate outflows.

2. THE MODEL

The formation of internal shock waves on a relativistic jet are commonly explained by different mechanisms, such as the interaction of the jet with inhomogeneities of the surrounding medium, the bending of jets and time fluctuations in the parameters of the ejection (Rees & Meszaros 1994; Mendoza et al. 2009). Here we are concerned with the latter.

According to the relativistic semi-analytical model of Mendoza et al. (2009) we describe a working surface and its kinetic luminosity power travelling inside an astrophysical jet. To do this, we consider a source ejecting material in a preferred direction with a velocity $v(\tau)$ and a mass ejection rate $\dot{m}(\tau)$, both dependent on time τ as measured from the jet's source (Mendoza et al. 2009). The

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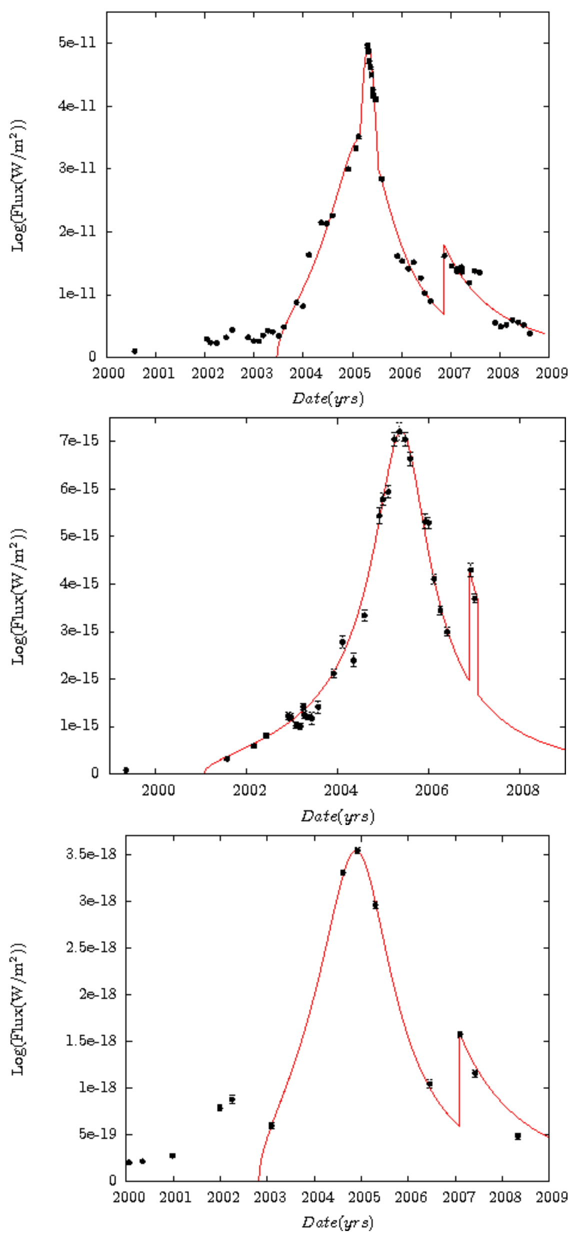

Fig. 1. From top to bottom the figure show the observed points of HST-1 in X-Ray, UV and Radio light curves from the observations (Harris et al. 2009; Madrid 2009; Chang et al. 2010) respectively. The continuous curve on the figure is the best fit to the observations using the semi-analytical model described in the text with a linear fit to the data yielding the ejection rates (see Table 1).

energy loss inside the working surface is calculated as the difference between the initial energy of the material and the energy of the flow inside the working surface. Assuming an efficient mechanism which converts all this kinetic energy into radiation power, then the total luminosity is given by $L := \mathrm{d}E_{\mathrm{r}}/\mathrm{d}t$,

TABLE 1

EJECTION RATES IN X-RAYS, UV AND RADIO

Wavelenght	$\dot{m}_{\mathrm{ini}}$	$\dot{m}_{\mathrm{second\ peak}}$
X-rays	5.59×10^{-7}	1.10×10^{-7}
UV	6.52×10^{-6}	1.78×10^{-6}
Radio	2.11×10^{-11}	3.48×10^{-12}

For all the data the units of $\dot{m}$ are in solar mass per year.

where $E_{\mathrm{r}} = E_0 - E_{\mathrm{ws}}$ is the radiated energy within the working surface (Mendoza et al. 2009).

In what follows we use the approach followed by Mendoza et al. (2009) in order to show that their model can describe the important features observed on the evolution of $HST-1$. To do so, the injected velocity is assumed to have a periodic variation given by $v(\tau) = v_0 + c\eta^2 \sin \omega\tau$, with a constant mass discharge $\dot{m}$ and a velocity of light c. We will present our results on the physical system of units for which $\dot{m}$ are dimensional constant.

2.1. *Fit to the data*

The data sample of HST-1 covers a period of time between the years 2000 to 2009. Since we use observations on different wavelengths, then it is best to normalise all observations to the intrinsic luminosity of HST-1. To do so, for X-rays we use the procedure developed in Harris et al. (2006), which gives a power law index for the flux of 1.5. For the UV data we use the flux density using the reference wavelength of the camera ACS/F220W at 2255.5 AA (Madrid 2009) and for the radio data a wavelength of 2 cm was used (Chang et al. 2010).

The X-ray light curve fit does not work with a simple variation of the velocity and so, we additionally adopt a periodic variation on the injected mass given by $\dot{m} = \dot{m}_i + \psi \sin \Omega$ just for the first flare. After the main peak (see Figure 1), the standard assumption made above fits quite well the observations. The local peaks can be easily modelled by assuming a rapid variation on the value of the discharge $\dot{m}$ injected in the jet according to the high variability of the core of M87 (Harris et al. 2009).

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